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ABSTRACT

This document characterizes South African education as resulting in large numbers of students who are poorly equipped to meet academic requirements of first-year university courses, especially in science related disciplines. It reports on a study designed to investigate the learning problems of disadvantaged South Africans in an attempt to identify approaches that can be developed to help alleviate them. The study focused primarily upon the difficulties experienced by such students in dealing with kinematics sections of a first-year physics course. A person-to-person interview technique was used as the students worked through some typical kinematics problems. The analysis of the interviews yielded a list of deficient cognitive functions and nine instruments were developed to compensate for these deficiencies; the strategy required for the use of a specific concept was developed as the concept was taught. This new approach was first used in the Physics 1B class of the University of the Western Cape (Capetown, South Africa), the class being divided into Test and Control groups. Results for the use of the concepts showed a 30% difference in favor of the test group and also showed a high level of enthusiasm for the experiment on the part of the test group students. The study concluded that there seem to be three approaches to teaching thinking: (1) teaching thinking free of specific content; (2) integrating thinking skills into content material by providing thinking strategies to give more meaningful access to the content of a discipline; and (3) determining the requisite thought processes for understanding and using concepts and laws, and then making these explicit in the development of the relevant curriculum materials. This paper indicates what may be attempted in the third area. (TW)

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TEACHING THINKING IN SUBJECT-SPECIFIC CONTEXTS TO DISADVANTAGED SOUTH AFRICAN COMMUNITIES

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Introduction

South African education is presently characterized by large numbers of students who, judging from the poor results in their first year at university as well as in the school-leaving examination, are badly equipped to meet the academic requirements of first-year university courses, especially in science-related disciplines. For some seven years now a growing interdisciplinary research group at the University of the Western Cape (UWC), a Black university in South Africa, has been attempting:

a) To understand the constructions which students from mainly a third world context bring to the study of various disciplines;

b) To determine the cognitive reasons for the poor academic performance of these students; and

c) To develop suitable instructional materials based on the above determinations.

To date suitable work has been done in the areas of physics, accounting and geography.

The Constructivist perspective is now widely accepted by researchers in Science Education (Linn, 1986). It is abundantly clear that people bring to

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their study of any discipline many concepts which they have derived from their interaction with the world. The job of the teacher is greatly complicated by the need to address these existing ideas. Efforts to design special instruction that considers such preconceptions has been reported by Trowbridge and McDermott (1980), and Hewson (1981).

Similarly, the application of Piagetian Developmental Psychology to the learning problems of students is extensively documented. Some work has also been done specifically with disadvantaged students (Whimbey et al, 1980). Using the Information Processing approach, a more fine-grained analysis of the thinking processes as used especially in problem-solving has also been attempted (Reif, 1984). One of the most effective programs along these lines and aimed at educationally disadvantaged persons was designed by Feuerstein, et al (1979, 1980) in Israel. However, all Feuerstein's work has been in a content-free mode. The present study addresses the question of whether Feuerstein's approach illuminates the problems of disadvantaged South Africans and whether it can be incorporated into subject areas.

A Paradigm Within Which the Learning Problems of Disadvantaged Students can be Placed

Little has been reported in the literature on efforts to assist disadvantaged students achieve in science-related disciplines (McDermott et al, 1980.) The work of Feuerstein and his co-workers in Israel represent a major step forward in understanding the cognitive processes of disadvantaged persons. With its componential analysis of the thinking processes such people use or do not use, it provided important insights into the possible reasons why students at UWC were in fact experiencing such difficulty with science-related disciplines.

The power of the approach lies in the identification of cognitive deficiencies as being at the root of at least part, if not all, the "retarded performance" of disadvantaged students. The insights gained from Feuerstein's work enabled a more directed attack to be made on the problems that UWC students have in learning physics. It enabled socio-economic factors (about which very little can be done by teachers at university level) to be accepted and by-passed for the purpose of providing real assistance in physics to first year students.

The Feuerstein approach has influenced the research in three main ways:

i) It proposed that the determining characteristic of a disadvantaged person is the manner in which information is processed by that person.

ii) Feuerstein's Cognitive Map, A list of cognitive deficiencies proved invaluable in the following ways:

   a) It gave an idea of the types of problems in physics which could be used to test students in an effort to establish the degree to which certain cognitive operations were used and the extent to which certain cognitive functions were deficient.

   b) It provided an understanding of why certain sections of the physics course proved too difficult.

iii) A match was made between the cognitive characteristics highlighted in (ii) and the requirements of a particular section of the physics course. Suitable remedial materials were produced with special emphasis on the requirements for solving problems.

Identifying Student Difficulties in Dealing with Mechanics

An examination of the Feuerstein approach gave a preliminary indication of the possible reasons why students were experiencing so much difficulty with the kinematics sections of the first year physics course - a section ostensibly based on only a few simple equations. It was noted that since problem formulations in this section tended to be rich in data, students were possibly experiencing difficulty at the input (i.e. the data gathering) phase of the mental act. It was decided to test this premise using the person-to-person interview technique as the students worked through some typical kinematics problems (See Mehl, 1985). In addition to the thirty detailed interviews conducted, a specially designed test was given to students at the beginning of the academic year to determine the extent to which they had developed any ability to elaborate Newton's laws. Several difficulties were highlighted (For details, see Mehl, in press.)

Semantic Difficulties

The extent to which certain words used in the formulation of problems proved to mislead students was not only surprising, but also very illuminating. Some work in this field has already been done in South Africa with regard to the readability of science textbooks (Wegerhoff, 1981). The aspect highlighted in the present research relates to the extent to which students are able to decontextualize words which are in common use but have a particular scientific sense. An example is the term "work" in the situation where I do no work while holding up a heavy object, say a refrigerator. Further research in this area will undoubtedly provide meaningful insight into disadvantaged students' problems in understanding science since for many such students, English (the predominant language of science instruction for the majority of these students) is often a second or even a third language.

Error factors in Physics

Both the interviews and the written test highlighted a number of common errors (Pickthorne, 1983), which students display in the Mechanics section of the physics course. Some of these errors have already been documented by a number of researchers under the heading "misconceptions" (Helm & Novak, 1983). Other types of errors relating to the choice of graphical axes and the signs given to kinematic variables can easily be addressed by careful presentation of these ideas, taking into account the knowledge gained from this research about the nature of the confusion which often exists in students' minds regarding such operations.

Mathematical Difficulties

The interviews also demonstrated, not unexpectedly, that students experience difficulties with certain mathematical concepts. The question with disadvantaged students seems to be not whether but rather with what, they have mathematical difficulties. Translated into practical terms within a physics course this implies that an analysis needs to be made of the mathematical requirements of any section of the course with appropriate remediation being built into, or parallel to, the presentation.

Cognitive Difficulties

The Feuerstein theory was very useful in giving direction to the interpretation of the wealth of data which was generated by the interviews. Two related areas of difficulty clearly manifested themselves:

a) The manner of data interpretation (Input phase)

It was abundantly clear from the interviews that the majority of students did not interpret the data in the problems clearly and accurately. Indeed, what distinguished the good students from the others was the care with which the former clarified the various features of the problems to themselves as opposed to the haphazard and frequently inaccurate data analysis of the latter. Among those who had difficulty, two groups could be distinguished:

i) Those who were simply unstructured in their approach to the problem. When they were asked to visualize the problem carefully and to record important details they were able, with some help, to do so. They usually then proceeded to a solution fairly easily.

ii) The rest of the students seemed unable, despite help and prompting, to visualize the problems clearly or to give a qualitative evaluation of the problem. They were, of course, unable to solve the problems on their own.

The analyses of the interviews have yielded a list of deficient cognitive functions which have been related to those documented by Feuerstein (See Mehl, 1985). While a number of deficient cognitive functions can be mentioned, the one which proved to be of particular difficulty to almost all the students interviewed was the ability to relate two sources of information. Since this cognitive function is fundamental in establishing relationships it could well merit further investigation. Another cognitive operation which proved difficult was the ability to visualize clearly the key features of the problems. While it is one thing to know that these cognitive functions are deficient and to determine their influence on student achievement, it is quite another matter to know exactly why they are deficient. This would be an interesting area for future research.

b) The manner of data elaboration

The interview analyses showed clearly that students' difficulty in carefully analyzing data in a problem, influenced the manner in which they worked toward a solution of the problem. Apart from not being able to recognize cues in the problem statement which would lead them to either the necessary equations or procedure to follow to reach a solution, they also did not demonstrate any clear plan in their use of the equations necessary for a solution. Thus, for example, in using one or more of the three kinematic equations, many students did not carefully search through the data in the problem nor relate various features of the problem to determine the applicable variables. Instead, they would usually use any available numerical data. In effect, their approach to the problem showed no particular design or planning.

Physics Content Analysis in Terms of Cognitive Demand

Content Analysis

On the strength of the list of cognitive functions supplied by Feuerstein, it is possible to analyze any section of work to identify the cognitive functions necessary to understand and use the concepts in that section, especially in problem-solving.

Thus, for example, in teaching sections in kinematics, it must be recognized that the ability to analyze data effectively (input phase) is crucial if students are to obtain proper solutions to the problems. In teaching any section of a syllabus, therefore, it becomes necessary to determine:

i) Which phases of the mental act (input, elaboration, output) are necessary for understanding and/or applying the particular concept or content material in general?

ii) The particular cognitive functions within each phase which are necessary for proper understanding of a concept, (especially those which may be deficient in students)

iii) How instruction can be developed which acknowledge the necessity of these functions and which strengthen these abilities if they are lacking in the students.

iv) What is the best manner of cultivating the necessary thought-process? Is it possible, for example, to develop suitable laboratory practical work?

v) The cognitive requirements of any testing procedures.

The steps enumerated above may even supply one means of reducing the number of misconceptions which students develop, or of distinguishing misconceptions from cognitive problems.

It is necessary to place the claims of this paper as respects deficient cognitive functions in perspective: the claim that is made is that areas of cognitive deficiency exist in the disadvantaged students who are the subjects of this study and that once these deficiencies are identified, it is possible to compensate for them in particular areas by the development of suitable subject-related material. No claims are made that in so doing, permanent all-round improvement of these specific functions will take place, although in some cases it may. What is said is that since the application of the particular concept may require certain cognitive functions in addition to pure content, some effort must be made to assist the disadvantaged student, through

suitable ancillary material. The cognitive ability thus addressed, may not transfer to another section of physics where this specific cognitive ability is required. For example, if a student is assisted to do meaningful data collection in an area such as kinematics, it does not follow that he will now have acquired a cognitive function which he can use in studying electricity, although one would of course hope that this was indeed the case.

However, the recognition of cognitive functions needed to deal with specific areas in physics does enable the instructor to assess more meaningfully the difficulties which students may experience with that specific area. Also, the approach encourages the instructor to distinguish between content deficiencies (e.g. a weak mathematical background), misconceptions which the student may have, and cognitive deficiencies which may exist. Further, one may conjecture that a concerted effort to address cognitive difficulties across the entire area of physics, wherever it is possible, may indeed produce permanent cognitive improvement. The approach described here at the very least enables us to examine cognitive deficiencies which students have, provides us with the means of making a more realistic assessment of the students and goes some way to suggesting how, in context, an improvement in students' performance may be effected.

Ancilliary Physics Material

Nine instruments were developed in an effort to compensate for deficient cognitive functions both on input and elaborational phases (Mehl, 1978). Some of the ways in which this was done are as follows:

Input Phase; Data Analysis

a) Unplanned, impulsive and unsystematic exploratory behavior:

To systematize the manner in which students scan the available data, each of the nine instruments present an analysis of the nature and quantity of data necessary to use the concept covered. Two illustrative examples:

- In dealing with Newton's laws, there is a discussion of the importance of determining "the body" (Newton's First and Second laws), or "the two bodies" (Newton's Third Law) when applying the laws. Explicit mention is made of the inherent contradictions which qualified physicists happily live with but seldom explain to students. (For example, for purposes of Newton's first and second laws, a rope is not regarded as "a body", but it is when using Newton's third law.)
- In solving problems on relative velocity, the need to find four variables in the problem formulation is emphasized. The way in which some of these variables are stated implicitly in typical problems is made clear.

b) Blurred and sweeping perceptions:

In an attempt to prevent unfocused reading of problems, the initial discussion in each instrument stresses implications which might easily be missed. For example, in dealing with relative velocity, it is not necessarily apparent which velocities are at issue if the problem specifies a particular direction of motion or involves an interception or point of closest approach. This potential problem is made explicit.

c) Lack of precision and accuracy:

To prevent critical data from being overlooked, several data collection sequences implicit to the use of particular concepts were developed. In addition, the instruments contain specific mechanisms that oblige students to use the data correctly. For example, in the instrument on projectile motion, the 'point in question' in the problem is highlighted as being of fundamental importance when relating the data accurately to the problem situation, and the need to choose the direction for the axes is stressed.

Input/Elaboration Interface

d) Impaired use of two or more sources of information:

This has proved to be a particularly difficult function to address. The following are examples of attempts:

i) In discussing projectile motion, students frequently find it difficult to relate motion in x- and y- directions simultaneously, to the composite motion of the body. The theoretical discussion in the instrument attempts to do this and to develop understanding of the issue.

ii) In dealing with relative velocity, students experience difficulties visualizing the nature of the relative motion because they do not relate the movement of the two bodies but rather focus on the actual movements of each body. This difficulty is discussed in the first section of the instrument.

Elaborational Phase

(e) Expanding the depth of the planning search

To work against the haphazard manner in which students customarily approach problem-solving, the strategy or procedure required for the use of a specific concept, was developed as concept was taught. As the course progressed, students they were able to do this planning more and more rapidly. One student reported that he had tried the development of suitable strategies to good effect in a section of a zoology course.

It must be emphasized that these strategies were not given to students as prescribed problem-solving algorithms. Rather, students were encouraged to extract the planning procedure implicit to many of these physics concepts.

THE RESULTS

The Physics 1B class at UWC was carefully divided into Test and Control groups. It is significant that on the entrance test as well as on all other sections of the course, the two groups performed identically. Only in the Mechanics section were there differences.

March examination.

	Test	Control
Mechanics:	52.4%	28.5%
Optics:	26.7%	30.9%

June examination.

	Test	Control
Mechanics:	49%	36.6%
Thermodynamics:	30%	35%

The results for the various concepts with Test and Control groups show an average difference of 30% in favor of the test group on items based on the

nine concepts developed in the instruments. (Tests were the normal quarterly Physics departmental tests). These results are statistically significant at a 95% confidence level.

It is difficult to convey in writing the enthusiasm of the students in the test group in both years of the experiment. One author (M. C. M.) had, prior to this time, taught the Physics I class for four years and the change was remarkable. Especially rewarding was to listen to the failures of the previous year (1980) who were exposed to the new approach in 1981. Many commented on the new teaching strategy which they described as "new", "very clear", "very effective", "marvelous", etc. Indeed, throughout the three years of the experiment, other staff members frequently conveyed the many positive comments of students. The fact that the lectures and the tutorial session (frequently conducted as full class sessions and not in small groups) of the test group remained full for the duration of the course, is indicative of student enthusiasm.

Conclusion

There seem to be three approaches to teaching thinking:

1. Teaching thinking free of specific content. The work of Feuerstein (1980) and DeBono (1976) falls in this category.
2. Integrating thinking skills into content material by providing thinking strategies to give more meaningful access to the content of a discipline. An example is the work of Perkins (1986).
3. Determining the requisite thought processes for understanding and using concepts and laws and then making these explicit in the development of the relevant curriculum material.

Little has been done thus far in the third area. The discussion in this article gives an indication of what may be attempted and the effect it can have on student understanding.

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APPENDIX

A sample lesson from

LEARNING AIDS IN PHYSICS MECHANICS

by

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